Exploring the Moon in the 21st Century:
Themes, Goals, Investigations, and Priorities, 2008

Theme 2: Use the Moon to Prepare for Future Missions to Mars and Other Destinations

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- **Requested by the NASA Advisory Committee (NAC)**
  - "The NAC Science Committee recommends that the Lunar Exploration Analysis Group (LEAG) be tasked to prepare a "Lunar Goals Roadmap" that maps science goals to objectives, and to observations and measurements. This roadmap should include an assessment of needed technology developments, areas of potential coordinated activities for commercial and international participation, and potential feed-forward activities for the exploration of Mars and beyond."
- **A Community Effort Coordinated by the Lunar Exploration Analysis Group (LEAG)**
  - community input via website at the Lunar and Planetary Institute
  - NASA
- **Theme 1: Pursue scientific activities to address fundamental questions about the solar system, the universe, and our place in them**
- **Theme 2: Use the Moon to prepare for future missions to Mars and other destinations**
- **Theme 3: Extend sustained human presence to the Moon to enable eventual settlement**

Theme 2: Use the Moon to prepare for future missions to Mars and other destinations.

Hardware

Goal 2A: Identify and test technologies and systems on the Moon to enable robotic and human solar system science and exploration.

- Objective 2A-1: regenerative life support
  - Investigation 1: air revitalization
  - Investigation 2: water recovery
  - etc.
- Objective 2A-2: crew health systems
  - Investigation 1: countermeasures
  - Investigation 2: medical diagnosis/treatment
  - etc.
- Etc.

Operations

Goal 2B: Use the Moon as a test-bed for missions operations and exploration techniques to reduce the risks and increase the productivity of future missions to Mars and beyond.

- Objective 2B-1: crew autonomy
  - Investigation 1: automation
  - Investigation 2: mission/traverse planning
  - etc.
- Objective 2B-2: human-robotic interaction
  - Investigation 1: teleoperation
  - Investigation 2:
  - etc.
- Etc.

Goal 2A: Identify and test technologies on the Moon to enable robotic and human solar system science and exploration

- **While the Moon and Mars have different gravities and drastically different environments and soil properties, both are still hostile environments that require similar functional capabilities for humans to explore and live off Earth.**
- **The Moon will serve as a test bed for technologies that will enable sustained human exploration of Mars and beyond.**
  - Regenerative life support
  - In-situ resource utilization
  - Fission surface power
  - Robotics
  - Surface mobility and EVA
  - Habitation

Objective 2A-1: Develop the capability for regenerative life support systems

- Mass and volume needed for consumables for traditional, open-loop life support systems are quite large when the long duration of human missions to Mars are considered
- Regenerative, or closed-looped, life support systems will enable smaller and less massive design of human systems, and will give the crews a higher degree of self-sufficiency and mission autonomy
- **Investigation:** Test air revitalization technologies that generate oxygen, and removes carbon dioxide and trace contaminants
- **Investigation:** Test water recovery technologies that result in the production of potable water from human waste streams and other grey water producers
- **Investigation:** Test waste management technologies to handle manufactured and packaging waste, as well as human waste
- **Investigation:** Test plant growth technologies to produce food, generate oxygen through photosynthesis, and generate potable water through transpiration and evaporation

Objective 2A-2: Develop the capability for crew health systems

- Low-gravity, dust, radiation, and isolation will have combined or integrated effects on human biology at all levels and human psychology during long-duration exploration missions on planetary surfaces
- **Investigation:** Test countermeasure technologies that will assure human performance remains at an acceptable standard
- **Investigation:** Test medical diagnosis and treatment technologies to allow well-patient care as well as the treatment of illnesses/injuries on a planetary surface
- **Investigation:** Test long-term food storage technologies to ensure lasting nutritional value of foods stored for extended periods of time on a planetary surface

Objective 2A-3: Develop surface mobility capabilities that allow human crews to efficiently and safely explore the surfaces of the Moon and Mars

- Extensive extravehicular activity (EVA) will be needed for crews to work on and explore planetary surfaces
- Major surface features on the Moon and Mars, prime targets for intensive investigations, are on the order on many 10's to several 100's km apart, and capabilities beyond those used during Apollo will be needed to traverse these great distances
- **Investigation:** Test pressurized rover technologies that would allow crews to traverse distances of at least several 100s km away from a landing or outpost site, on surface exploration missions lasting up to several weeks
- **Investigation:** Test advanced space suit technologies that would allow greater mobility, dexterity, and range than the space suits used during the Apollo, Space Shuttle, and International Space Station programs.
- **Investigation:** Test robotic field assistant technologies to compliment and augment the abilities of human crew members exploring or working on a planetary surface

Objective 2A-4: Develop the capability to acquire and use local resources to sustain long-term exploration and habitation of planetary surfaces

- The Moon and Mars possess abundant natural resources that could be used to supply human consumables, such as air and water, and construction materials
- Relying on earth-based supplies for extended operations on the Moon and Mars is likely neither affordable or sustainable, and achieving a certain level of self-sufficiency would also reduce the risks involved with the delivery of those supplies
- **Investigation:** Test resource extraction technologies needed to acquire feedstocks from planetary regoliths
- **Investigation:** Test chemical processing technologies to produce oxygen from planetary regoliths
- **Investigation:** Test technologies to produce volatiles from dry or frozen regoliths
- **Investigation:** Test electrolysis technologies (e.g., water, carbon dioxide)
- **Investigation:** Test phase separation technologies for handling solids, liquids, and gases
- **Investigation:** Test product storage technologies
- **Investigation:** Test technologies to produce construction materials or paved/prepared surfaces

Objective 2A-5: Develop the capability to produce adequate levels of power on planetary surfaces to allow human crews to work and live productively

- Studies of initial planetary outposts have shown power levels in the several 10's of kw are needed on a continuous basis for sustained human operations
- When resource development is considered in addition to the outposts, the power levels increase to many 10's of kw, and sometimes to a few 100's of kw
- **Investigation:** Test fission power system technologies
- **Investigation:** Test solar concentrator/collector photovoltaic array technologies that concentrate diffuse, or low level, solar energy
- **Investigation:** Test radioisotope thermal generator technologies for small remote science stations and observatories
- **Investigation:** Test energy storage technologies for fixed and mobile surface applications

Objective 2A-6: Develop the capability to autonomously land safely and accurately on the Moon and Mars

- The surfaces of the Moon and Mars are unprepared surfaces with natural hazards such as boulders, craters, and sloping terrain
- Once a facility is established on a planetary surface, launch and landing zones will be given designated locations
- **Investigation:** Test autonomous surface hazard avoidance technologies for lunar landing spacecraft to ensure safe landings
- **Investigation:** Test landing aid/beacon technologies on the lunar surface to ensure accurate landings of lunar surface bound spacecraft at a pre-designated surface location

Objective 2A-7: Develop the capability to provide or construct structures on planetary surfaces adequate for long-duration habitation by humans, and made of materials that will endure extended exposure to the deep-space environment

- Unlike the Apollo missions where the astronaut crew lived out of their lander vehicle, sustained presence on the Moon or Mars will require the use of pressurized habitats emplaced on the planetary surface
- Sustained presence on the Moon or Mars will require structural materials that can retain their integrity for extended periods of time after continuous exposure to radiation, micrometeoroids, and extreme temperatures
- **Investigation:** Test inflatable habitat technologies on the lunar surface
- **Investigation:** Test long-duration exposure of advanced material technologies on the Moon
- **Investigation:** Test manufactured structures technologies that use construction materials made from natural lunar resources

Objective 2A-8: Develop the capability for crews on the Moon or Mars to communicate with other assets on the surface, and navigate to and from those assets

- Working and living on the Moon and Mars will involve traveling long distances, over the horizon from any established facility, and likely beyond line-of-sight of any fixed communication or navigation asset at that facility
- Neither the Moon or Mars have a strong global magnetic field available for surface navigation
- **Investigation:** Test over-the-horizon and line-of-sight communications technologies on the lunar surface
- **Investigation:** Test technologies for navigating on the lunar surface without a strong magnetic field

Objective 2A-9: Develop the capability for human crews to operate safely on planetary surfaces, protected from the extreme environment and inherent natural hazards

- Due to the lack of measurable magnetic fields and the existence of thin or very tenuous atmospheres, humans working and living on the Moon and Mars will be immersed in environments with higher levels of radiation and micrometeoroid impacts than on Earth
- Other environmental hazards like dust and extreme temperatures will effect design of all planetary surface systems
- **Investigation:** Test radiation shielding technologies to protect astronauts on the lunar surface from galactic cosmic rays (GCR) and solar energetic particle (SEP) events
- **Investigation:** Test micrometeorite protection technologies to prevent damage caused by micrometeorite impacts
- **Investigation:** Test dust mitigation technologies to prevent dust from interfering with mechanical systems and causing health problems for astronaut crews
- **Investigation:** Test thermal management technologies to handle the large diurnal temperature difference that occurs on the lunar surface
- **Investigation:** Test forward and backward planetary protection technologies to prepare for human and robotic operations on Mars.

Goal 2B: Use the Moon as a test-bed for mission operations and exploration techniques to reduce the risk and increase the productivity of future missions to Mars and beyond

- **The nearness of the Moon with respect to Earth allows for opportunities in testing of surface mission operations and exploration techniques without the concern that help from Earth or the ability of the crew to return safely is more than a year away.**

- **The Moon will serve as a training ground for mission operations that will enable sustained human exploration of Mars and beyond.**
  - Crew autonomy
  - Human-robotic interaction
  - Human performance

Objective 2B-1: Develop the capability for autonomous crew operations on the Moon and Mars

- The great distances between the Earth and Mars, and the associated time delays in communication make real time control of mission operations from Earth difficult
- While the Apollo missions to the moon were scripted minute by minute, long-duration missions on the Moon and Mars will need to be more goal oriented on a weekly or monthly basis
- Crews on the surface of the Moon or Mars should be able to plan and adjust their work and exploration schedule based on discoveries made in the field, or the lack of progress made on current investigations or operations
- **Investigation:** Test integrated system health management techniques to autonomously monitor system performance and remedy repairs to underperforming systems with little or no crew intervention
- **Investigation:** Test crew-centered planning and scheduling techniques to allow exploration crews tactical control of their workload
- **Investigation:** Test automated sampling documentation techniques to allow crews to quickly document all steps involved in the acquisition and curation of geologic samples on the Moon or Mars
- **Investigation:** Test the execution of mission operations with extravehicular activities (EVA) and intravehicular activities (IVA) without the control from Earth

Objective 2B-2: Develop the capability for productive and efficient human-robotic interaction in the exploration of planetary surfaces

- Robotic explorers can be used to augment and compliment the explorations of human crews, thus making more efficient use of astronaut time for complex tasks that require human cognitive skills and dexterity
- **Investigation:** Test teleoperation techniques to allow human crews on the lunar or martian surface to control and direct robotic explorers
- **Investigation:** Test robot interface techniques that will allow human crews on the lunar or martian surface to operate a multitude of different types of robots with a single computer interface

Future Work

- **The Mars Exploration Program Analysis Group (MEPAG) Mars Science Goals, Objectives, Investigations, and Priorities document is now 8 years old.**
- **The Lunar Exploration Analysis Group (LEAG) Exploring the Moon in the 21st Century document is less than 8 months old.**
- **For Theme 2, there is a lot of hard work ahead of us to get the desired detail into the LEAG lunar document.**
  - Have only reaffirmed (reproduced) NASA Exploration Strategy Objectives
  - Finding the right subject matter experts (SMEs) is not trivial
  - Finding SMEs to volunteer (e.g., work for free) is not trivial
  - There is a certain level of 'roadmap burnout' that exists
  - NASA ESMD Exploration Technology Development Program (ETDP) is conducting the same process as Theme 2

"For fans tuning in late, we are in the top of the first inning, with a runner on first base"

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The Moon or Bust										
Forget the Moon										

Participants

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Theme 2: Use the Moon to prepare for future missions to Mars and other destinations.

Hardware

Goal 2A: Identify and test technologies and systems on the Moon to enable robotic and human solar system science and exploration.

Objective 2A-1: Develop the capability for regenerative life support systems

Objective 2A-2: Develop the capability for crew health systems

Objective 2A-3: Develop surface mobility capabilities that allow human crews to efficiently and safely explore the surfaces of the Moon and Mars

Objective 2A-4: Develop the capability to acquire and use local resources to sustain long-term exploration and habitation of planetary surfaces

Objective 2A-5: Develop the capability to produce adequate levels of power on planetary surfaces to allow human crews to work and live productively

Objective 2A-6: Develop the capability to autonomously land safely and accurately on the Moon and Mars

Objective 2A-7: Develop the capability to provide or construct structures on planetary surfaces adequate for long-duration habitation by humans, and made of materials that will endure extended exposure to the deep-space environment

Objective 2A-8: Develop the capability for crews on the Moon or Mars to communicate with other assets on the surface, and navigate to and from those assets

Objective 2A-9: Develop the capability for human crews to operate safely on planetary surfaces, protected from the extreme environment and inherent natural hazards

Operations

Goal 2B: Use the Moon as a test-bed for missions operations and exploration techniques to reduce the risks and increase the productivity of future missions to Mars and beyond.

Objective 2B-1: Develop the capability for autonomous crew operations on the Moon and Mars

Objective 2B-2: Develop the capability for productive and efficient human-robotic interaction in the exploration of planetary surfaces